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PRELIMINARY DEVELOPMENT AND TESTS OF A BLAST-CLOSURE VALVE

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PRELIMINARY DEVELOPMENT AND TESTS OF A BLAST-CLOSURE VALVE

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Type C

by

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ABSTRACT

The ventilation systems of shelters providing blast protection must have automatic valves to prevent ingress of damaging pressure waves through the air ducts. This report discusses a 600-cfm blast-actuated closure valve being developed at the U. S. Naval Civil Engineering Laboratory for overpressure up to 100 psi.

A series of air-flow and blast tests have been performed which show that the valve has the potential to satisfy all of the desirable criteria but requires further development.

INTRODUCTION

All personnel shelters which are going to be occupied for more than a few hours must have ventilation. This normally requires air intake and exhaust ducts to the outside atmosphere. If the shelter is to provide blast protection, the ducts must be equipped with some sort of device to prevent a blast wave from entering the sheltered area via the ventilation system.

Such a device should be automatic, inexpensive, reliable, reusable, and maintenance free. It should not allow large pressure impulses to pass by the valve before closure, nor cause excessive obstruction to the rated air flow either before or after the passage of a blast wave, nor should it require personnel to expose themselves to a hostile environment to service the device after each operation. Also, it should operate in such a manner as to prevent excessive amounts of air loss from the shelter during periods of negative pressure. Inasmuch as a device meeting all of the desirable characteristics did not seem to be available, this Laboratory undertook the development of a closure device suggested by the author. This report covers the work accomplished to date, the present state of development, and the future plans (see Appendix).

In order to have all of the desirable functional features, a blast-closure valve must be kept operationally simple. This can best be done by avoiding the complexities of thermal and radiation detecting and triggering systems, and by using the blast wave itself to activate the closure device and provide the necessary source of power.

There is a disadvantage to a blast-actuated closure valve, however, in that it cannot close instantaneously but does take a finite, if small, length of time to become completely closed. During this time a portion of the blast wave bypasses the valve. The pressure impulse bypassed is normally large enough to cause filters to rupture. A long duration overpressure of 2 psi for example might be taken as typical of that causing filter damage. The usual solution to this problem has been to provide plenum chambers in which the wave could expand and be attenuated. Large plenums however can be expensive and undesirable in themselves. To avoid this disadvantage a blast-actuated valve was conceived in which the blast wave had to travel an adequate distance after actuating the valve and before reaching the closure port. The bypassed wave could thereby be eliminated or considerably reduced.

DESCRIPTION OF VALVE

The valve under development was for an air flow of 600 cfm and for use with 8-inch standard steel pipe. It would probably be installed in the duct

system external to the shelter (i.e., buried in the ground) but could be placed within the shelter is so desired. Other size valves could be developed.

The body of the valve consists of two adjacent chambers which are connected at the bottom by a length (loop) of external pipe. The only moving part is a "v"-shaped flap that is hinged at the apex with one arm hanging in each chamber. Figure 1 shows a full-scale wooden and plastic model of the valve ready for the initial air-flow tests, and Figure 2 shows a full-scale metal model of the valve prior to the initial Blast-Simulator tests. The valve body was fabricated from 5/8-inch-thick Cor-Ten steel plate and weighed about 240 pounds. It was about 12 inches high, 10 inches deep, and 34 inches wide.

The loop of steel pipe connecting the two chambers in the body of the valve was used to provide a distance through which the blast wave could travel while the valve was closing. Two different loop lengths and two different loop configurations were evaluated.

For all tests the flap (i.e., "v"-shaped moving part) was fabricated from aluminum. The first flap was for the air-flow tests only and did not receive any special treatment. The second was fabricated from 6061-T6 plate and rod, welded with 4043 filler, and given a solution and precipitation heat treatment to T6. It had an angle between the faces of the flap of 90 degrees. The third flap was made of the same material and given the same heat treatment, but had a slightly different design at the apex and 110 degrees between the faces of the flap. The second and third flaps are shown in Figures 3 and 4. They weighed 5-1/2 pounds each.

To determine the mechanical properties of the materials used, a butt weld was made using Cor-Ten steel plates and two butt welds using aluminum. The aluminum was then heat treated along with the flaps. Standard specimens were machined from each, and tensile tests were performed. The results were as follows:

STEEL

Yield point	55,000 psi
Ultimate Strength	73,000 psi
Elongation in 8 inches	7.8 %
Modulus of Elasticity	28.4×10^6 psi

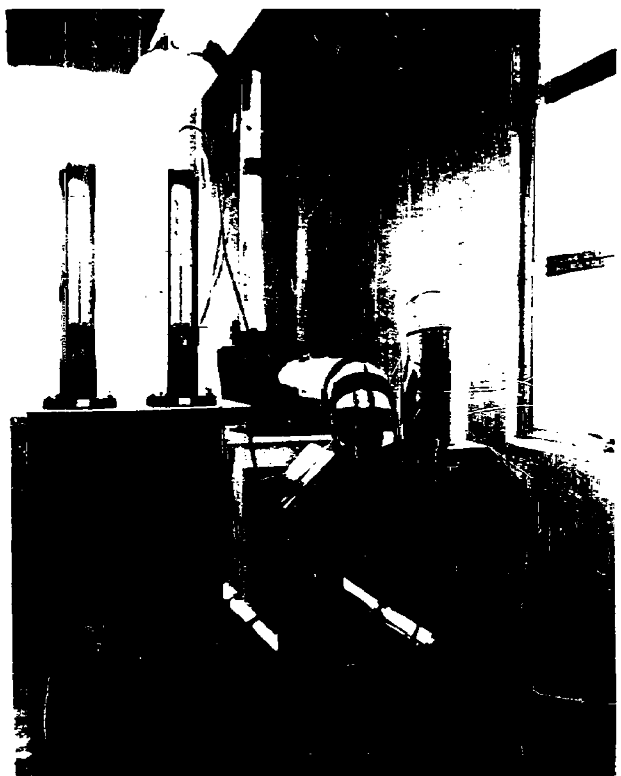


Figure 1. Mock-up of valve ready for initial air-flow tests.

Figure 2. Metal model of valve prior to initial blast-simulator tests.

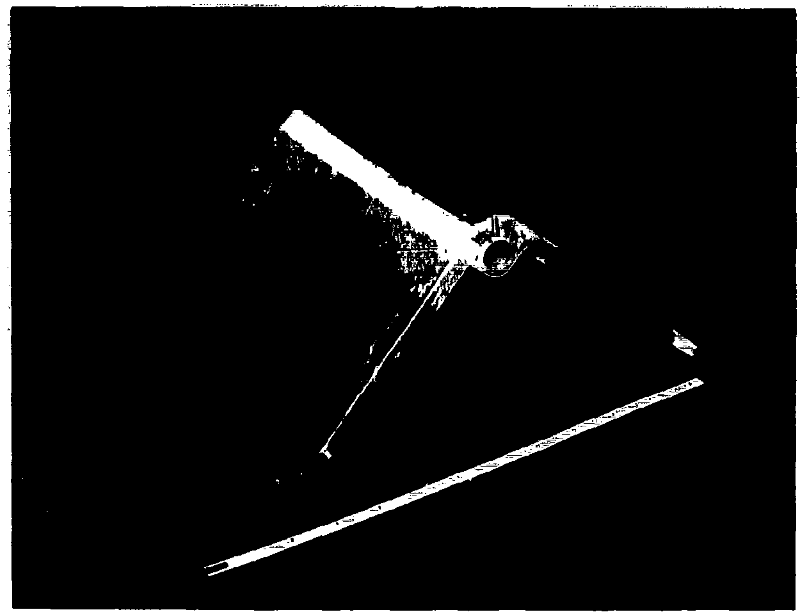


Figure 3. 90-degree flap.

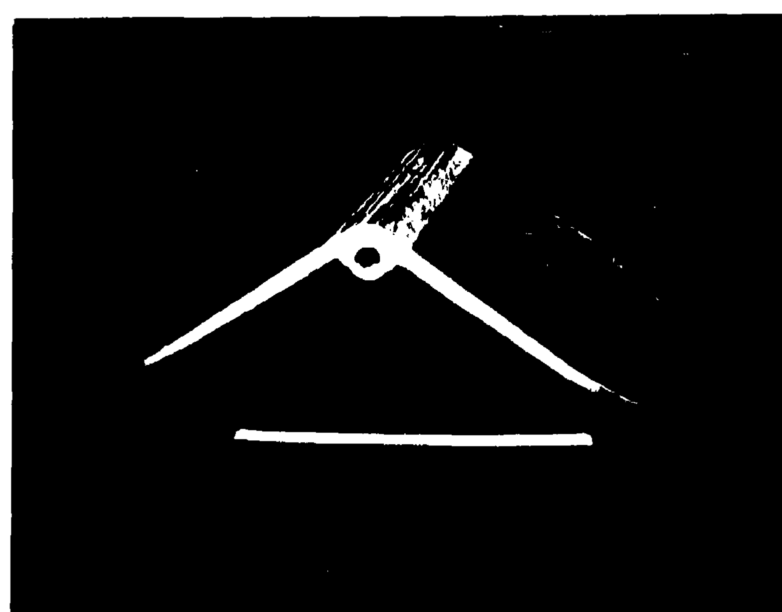


Figure 4. 110-degree flap.

ALUMINUM

Ultimate Strength	22,000 psi
Elongation in 8 inches	0.39 %
Modulus of Elasticity	9.9×10^6 psi

All failures were in the welds. The aluminum had only about half the expected strength and was very brittle. The reason for this is unknown.

The valve is installed so that the flap is held open by the force of gravity. A small ball plunger may be used on each side of the flap near the apex to help keep the valve open during normal air flow, but is not necessary with the 90-degree flap. Normal air flow can be through the valve in either direction.

A blast wave traveling through the duct would enter the valve and impinge upon one side of the flap, thus exerting pressure on this part and causing it to rotate about a hinge at the apex and to close the opposite port. The opposite port would be essentially closed by the time the blast wave reached there. If the port was not closed, the pressure on the back of the flap would cause it to finish closing and would hold it closed until the over-pressure was gone. For the negative phase, the flap would flip over and close the other port. Thus, in effect, any abnormal pressure differential on either side of the valve causes it to close and remain closed as long as that pressure differential exists.

AIR-FLOW TESTS

A number of air-flow tests were conducted on a mock-up of the valve to determine the pressure loss through it at its designed air-flow rate and to determine the effects of various modifications.

The test set-up is shown in Figure 1. The model was attached to the intake side of a heavy duty centrifugal blower to simulate actual use of the valve on the air intake of a protective shelter. All joints and seams of the blower and duct-work were sealed to prevent leakage and to insure accurate air-flow measurements. It was not possible to obtain the desired air flow of 600 cfm with the available equipment but as will be seen, the measured air flow was close enough to this figure for all practical purposes.

It was necessary for a convenient laboratory test of the valve to include two additional 90-degree elbows in the loop between the two chambers. The pressure loss across these elbows must, of course, not be charged against the valve. Calculated pressure loss for a 90-degree elbow at 600 cfm is approximately 0.12 inch H_2O. Measured pressure loss was about 0.2 inch H_2O for each elbow. Allowing for possible experimental error, a conservative compromise total pressure loss for the two elbows was taken as 0.3 inch H_2O.

Air flow was measured on the discharge side of the blower with a standard Pitot tube. Pressure taps were located before and after each component of the valve or section of duct-work expected to contribute to the total pressure loss as shown in Figure 5. Pressure measurements were made with a Merian micro-manometer.

Tests were conducted with two different configurations at the bottom of the pipe loop connecting the two chambers, as can be seen in Figure 5. One was with a blast-trap section installed and one was with the blast-trap replaced with a standard long-radius pipe return. Additional tests were made with the flap support grill removed, with a different shape grill installed, and with minor interior modifications to check their effect in reducing pressure loss. The 90-degree flap was used for all tests conducted on the model.

Tables I and II list the air flow and pressure drop data obtained from the model tests. The results show that with the blast trap in the pipe loop the total pressure loss was 0.82 inch of water. Without the blast trap (with the long-radius pipe return) the total pressure loss was 0.76 inch H_2O. It should be noted that these are losses between points 1 and 2 as shown in Figure 5 and do not include any losses that would occur prior to or after these points in a normal distribution system.

In these tests it was found that the flap would stay open under the normal air flow without the aid of the ball plungers. They did, however, help to steady the flap in the desired position. It was also noted that the flap could be moved through a significant angle without causing large increases in the pressure drop across the valve.

The miscellaneous tests conducted with various shaped flap-support grills and interior modifications (see Figure 6) showed that the total pressure loss could be reduced by about 0.15 inch H_2O with the proper combination. The metal prototype for the blast tests was therefore fabricated with the ends of the body straight, a T-shaped flap-support grill, and less overall body height.

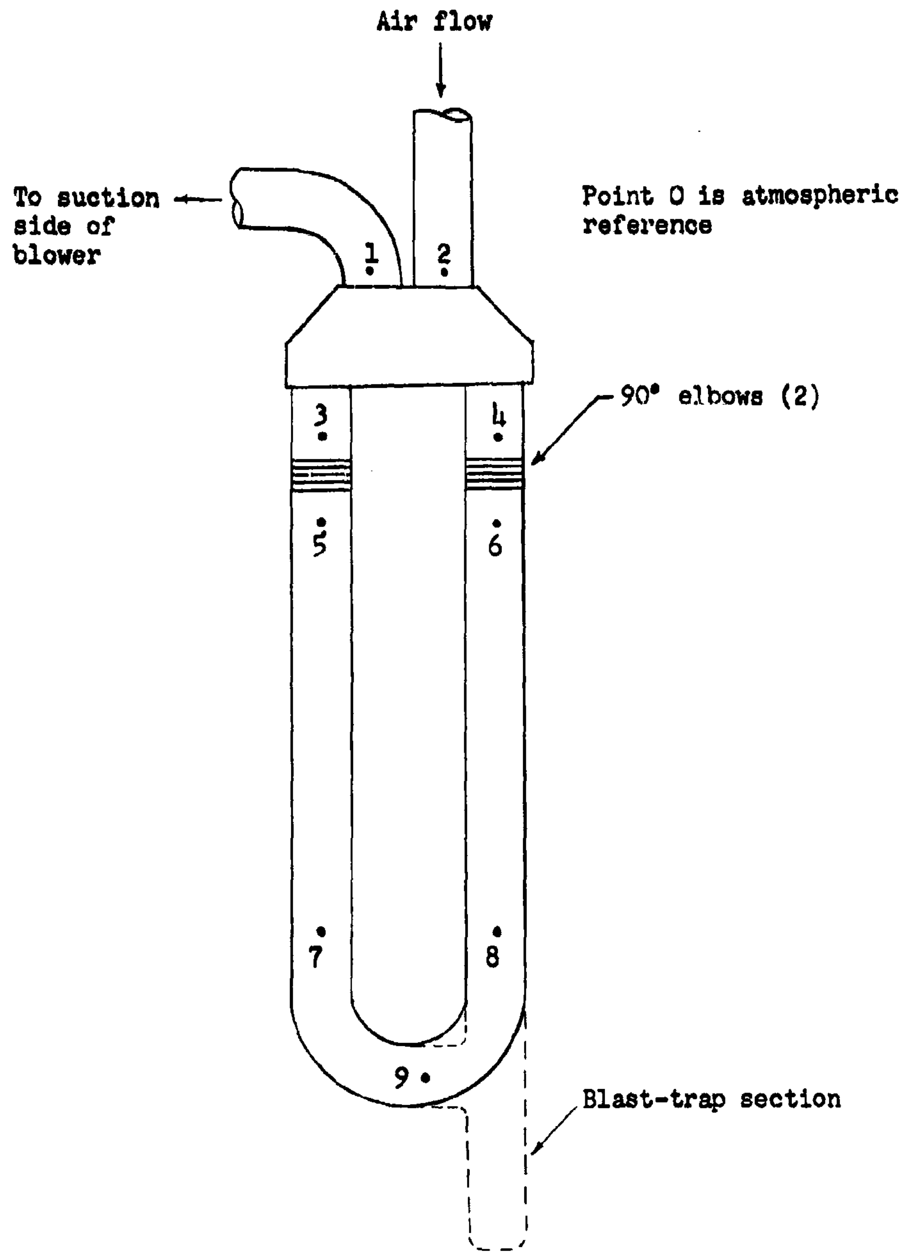
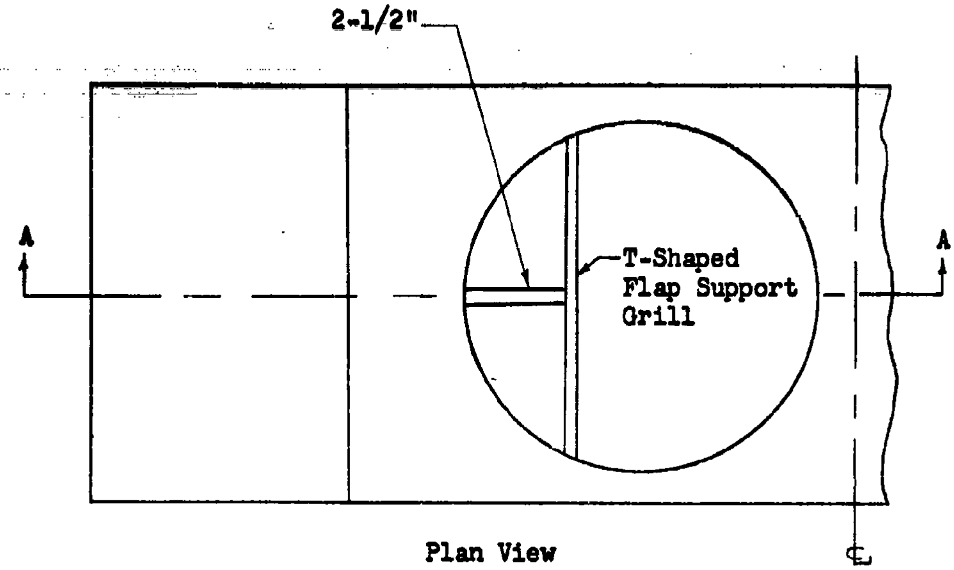


Figure 5. Pressure tap locations for air-flow tests.



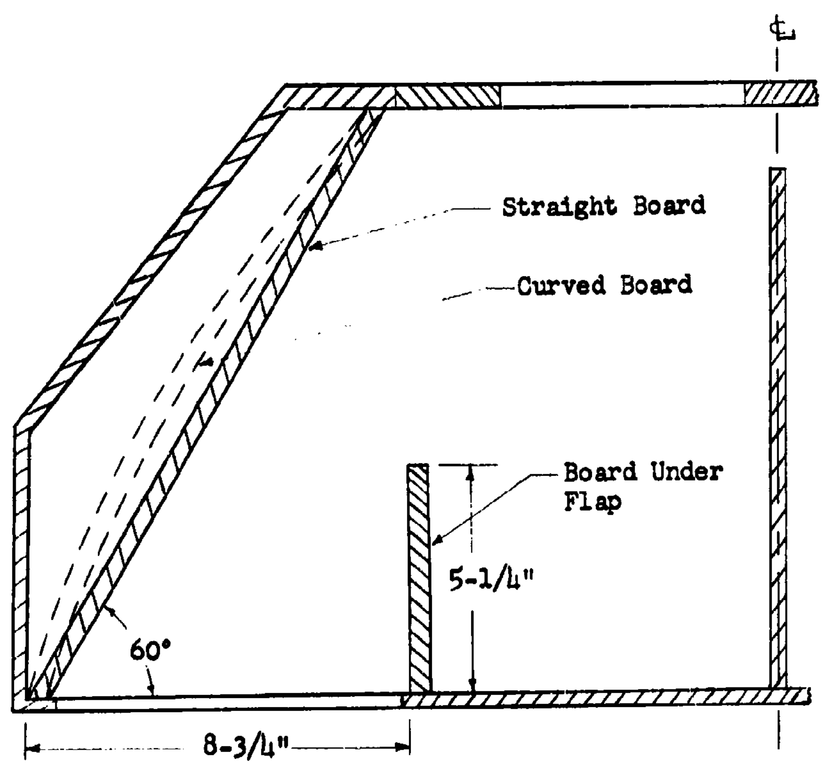


Figure 6. Various modifications evaluated during air-flow tests.

Table I. Air-Flow Pressure Losses, 90-degree Flap

With Blast Trap (A)			Without Blast Trap (B)		
Between		Pressure Loss	Between		Pressure Loss
Tap	Tap	(inches of H_2O)	Tap	Tap	(inches of H_2O)
0	2	0.420	0	2	0.471
1	2	1.115	1	2	1.055
1	3	0.451	1	3	0.452
1	4	1.075	1	4	1.017
1	5	0.650	1	5	0.676
1	6	0.884	1	6	0.835
1	7	0.622	1	7	0.669
1	8	0.852	1	8	0.867
1	9	0.710	1	9	0.699
2	3	0.670	2	3	0.600
2	4	0.042	2	4	0.037
2	5	0.475	2	5	0.390
2	6	0.256	2	6	0.214
2	7	0.523	2	7	0.415
2	8	0.290	2	8	0.176
2	9	0.418	2	9	0.355
3	4	0.624	3	4	0.565
3	5	0.200	3	5	0.226
3	6	0.433	3	6	0.391
3	7	0.180	3	7	0.216
4	5	0.445	4	5	0.358
4	6	0.201	4	6	0.200
4	8	0.235	4	8	0.370
5	6	0.248	5	6	0.182
5	7	Negligible	5	7	Negligible
5	8	0.213	5	8	0.114
5	9	0.090	5	9	0.035
6	7	0.277	6	7	0.196
6	8	0.040	6	8	Negligible
6	9	0.173	6	9	0.160
7	8	0.245	7	8	0.288
7	9	0.115	7	9	0.049
8	9	0.150	8	9	0.191

Air Flow = 590 cfm　　　Air Flow = 580 cfm

Total Losses (less loss for two 90° elbows)

(A) With blast trap: 1.12 - 0.30 = 0.82" H_2O

(B) Without blast trap: 1.06 - 0.30 = 0.76" H_2O

Table II. Air-Flow Pressure Losses, Miscellaneous Tests

1. Without Grill - air flow = 586 cfm
   Pressure loss (tap 1-3) = 0.325" H_2O
   Pressure loss (tap 1-2) = 0.965" H_2O

2. With Grill - air flow = 593 cfm
   Pressure loss (tap 1-3) = 0.415" H_2O
   Pressure loss (tap 1-2) = 1.050" H_2O

3. With Straight Board - original grill - 590 cfm
   Pressure loss (tap 1-2) = 0.955" H_2O

4. With Curved Board - original grill - 590 cfm
   Pressure loss (tap 1-2) = 1.025" H_2O

5. With Curved Board - new grill - 590 cfm
   Pressure loss (tap 1-2) = 0.850" H_2O

6. With Straight Board - new grill - 590 cfm
   Pressure loss (tap 1-2) = 0.853" H_2O

7. With Straight Board - no grill - 590 cfm
   Pressure loss (tap 1-2) = 0.920" H_2O

8. Straight Board - board under flapper - no grill - 590 cfm
   Pressure loss (tap 1-2) = 0.905" H_2O

9. Straight Board - board under flapper - new grill - 590 cfm
   Pressure loss (tap 1-2) = 0.813" H_2O

Air-flow tests were also conducted on the metal prototype complete with a pipe loop 21 feet 10 inches long using the standard 180-degree long-radius return at the bottom. The valve was tested with both the original (90-degree) and the modified (110-degree) flaps. The ball plungers were necessary to keep the 110-degree flap open during the normal air flow. Only the overall pressure drop across the valve and pipe loop (between points 1 and 2 of Figure 5) was measured. The results were approximately as follows:

90° flap, 0.65 inch pressure drop at 590 cfm

110° flap, 1.02 inches pressure drop at 575 cfm

These values are satisfactory and in line with other losses which would occur in shelter ventilation systems. There would also be intake losses, losses through the filters, and distribution losses dependent upon the systems.

BLAST-SIMULATOR TESTS

Two series of tests were conducted in the NCEL blast simulator to determine the following:

1. Relative peak pressures and impulses to which various portions of the system would be subjected
2. Closure times under various overpressures
3. Magnitude of the rebound problem
4. Effect of different flap angles
5. Effect of the ball plungers on closure time
6. Angular accelerations of the flap
7. Strains in the valve body and the flap as related to time
8. Ability of the whole system to repeatedly withstand the design overpressure of 100 psi
9. Effectiveness of the blast-trap section in the loop
10. Magnitude and duration of any portion of the blast wave which bypassed the valve

Instrumentation consisted of six Statham pressure cells, two Flipip pressure transducers, eight SR-4 strain gages, two Statham accelerometers, and one device on the axle of the flap to measure its rotation. These nineteen channels of information were connected with CEC System-D power supplies and amplifiers and were recorded on two CEC oscillographs.

Figure 7 shows the location of most of the instrumentation. There were also two pressure cells (Nos. 1 and 2) located in the skirts of the simulator, and a strain gage (No. 8) located on the flap.

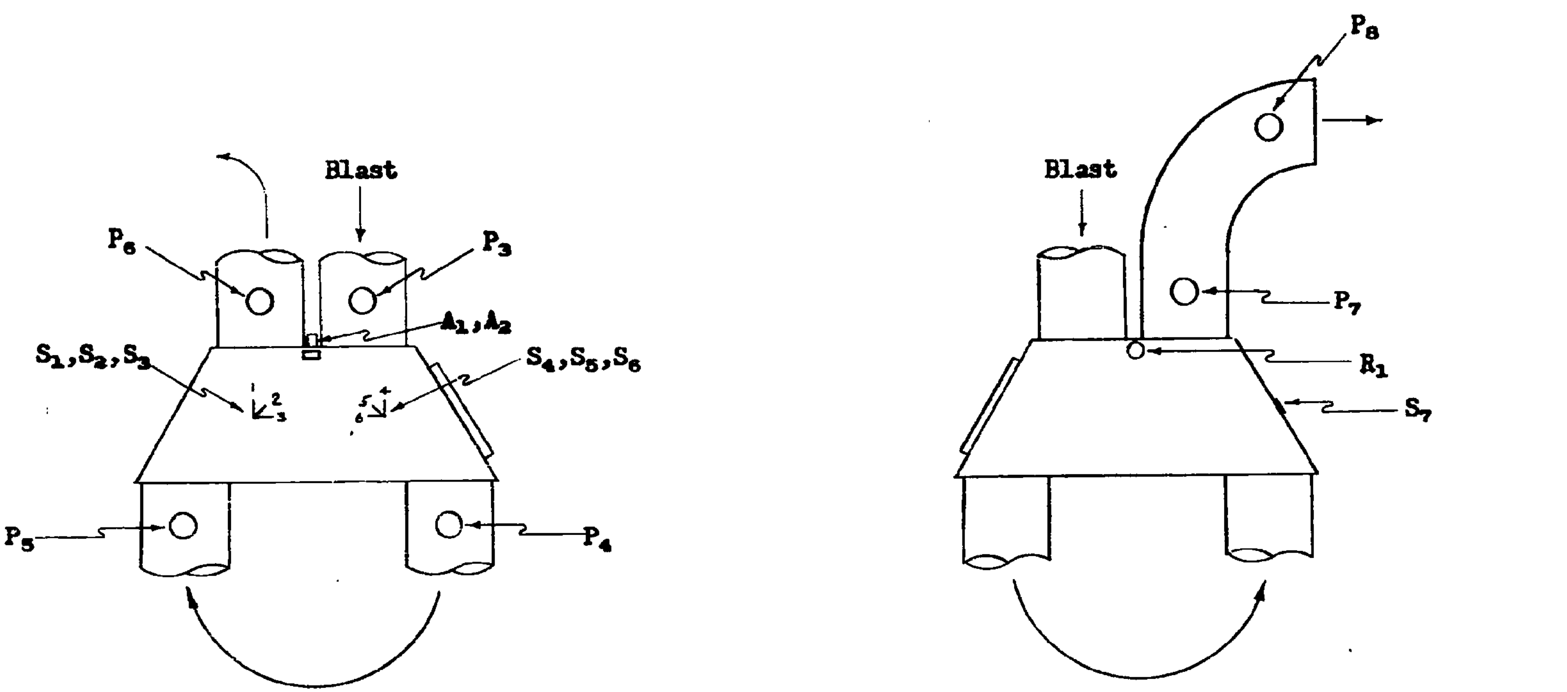
The blast-closure valve and its associated duct-work were attached to the blast simulator as shown in Figure 8. The shelter side of the valve was exhausted to the atmosphere.

During the blast tests the valve was subjected to a range of peak overpressures from 11 to 113 psi as measured between the skirts of the simulator. The blast waves generated by the simulator had a decay typical of the idealized wave form from a nuclear weapon. The pressures measured at points 3, 4, and 5 (Figure 7) also had about the same peak value as that measured in the simulator, but a considerably different wave form. When a given wave traveled through the blast-closure system it was attenuated until it reached the closure port. At that point it was reflected and traveled back through the entire system. The peak values of the reflected wave were about equal to the initial peak pressures measured in the simulator. At point 3 they averaged 94 per cent, at point 4 they were 95 per cent, and at point 5 they averaged 99 per cent. The velocity of the initial wave front through the 8-inch-diameter pipe loop ranged from about 1300 feet per second for the low pressure to about 1900 feet per second for the high pressure.

Initial closure times ranged from 6 to 26 msec for the 110-degree flap and from 16 to 33 msec for the 90-degree flap. Two of the rotation-vs-time curves for the 110-degree flap are shown in Figure 9. The arrival time of the blast wave at the closure port ranged from 12 to 18 msec during the tests of the 110-degree flap.

After initially closing, the flap would usually rebound a couple of times as can be seen in Figure 9. For the 110-degree flap the final closure times ranged from 16 to 40 msec.

One test was made to determine the increase in initial closure time due to the ball plungers used to restrain the movement of the flap during normal air flow. The ball plungers were removed and a previous low pressure test duplicated. The flap closed about 6 per cent faster without the ball plungers.



P = Pressure cell
S = SR-4 strain gage
R = Rotation of flap
A = Accelerometer

Figure 7. Instrumentation for blast-simulator tests.

Figure 8. Valve ready for blast-simulator tests.

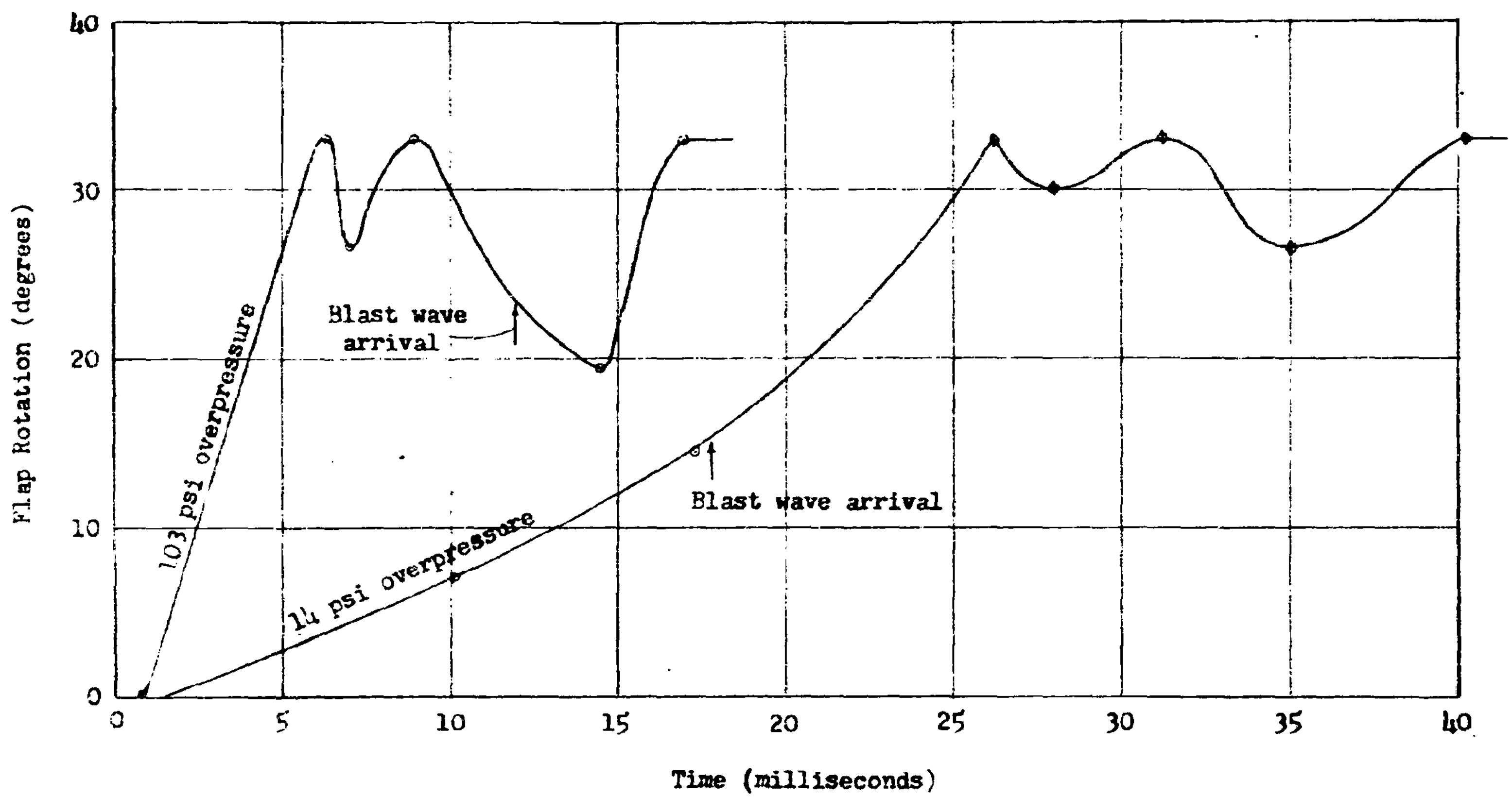


Figure 9. Flap rotation versus time for a high pressure and a low pressure test.

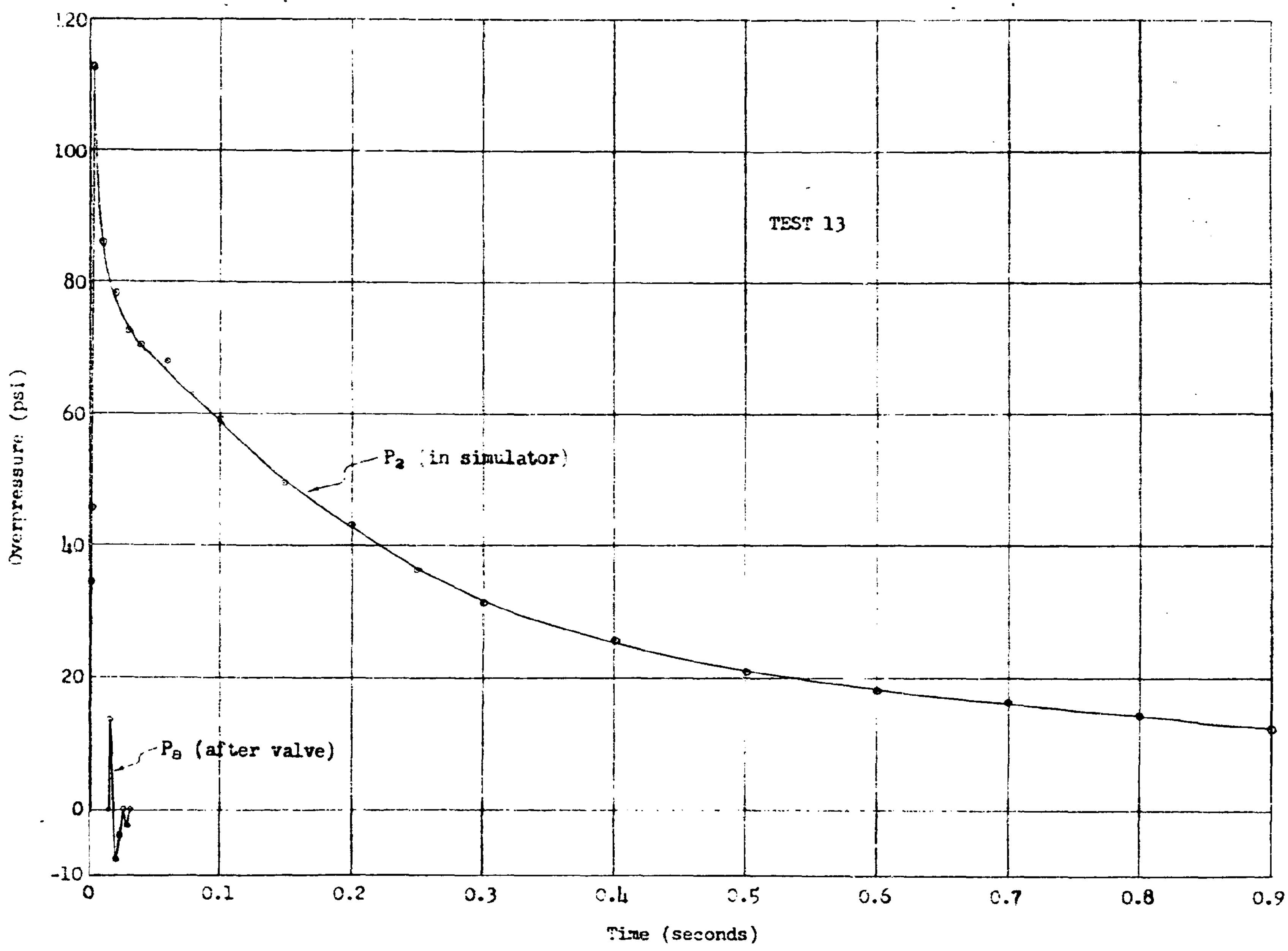


Figure 10. Bypassed pressure wave compared to applied pressure wave.

This, however, was probably within the range of experimental error.

During all tests the angular accelerations of the flap were very high. But at no time did the inertial effects before closing ever become large enough to cause a permanent reduction of the dihedral angle between the arms.

A few measurements were made of the strains in the flap. The arm first loaded by the blast wave would initially deflect in the direction of rotation. While continuing to rotate, it would then spring back in the opposite direction and continue to oscillate until the other arm hit the closure port. At that time it would make a large deflection in the direction of rotation, and then spring back again in the opposite direction. The largest strain recorded before closure was 2,450 microinches per inch.

The body of the valve was instrumented with seven strain gages. The recorded strains were, however, all very small. The largest, about 280 microinches per inch, was in the center of the end plate, gage 7, Figure 7.

The valve was subjected to four tests in which the peak pressure was over 100 psi. At no time did any part of the valve body or the pipe show any permanent deformation. As was expected, however, the aluminum flap was slightly bowed after the tests. The maximum was about 3/16 inch, but this did not impair its operation or effectiveness.

The effectiveness of the blast-trap section in the loop was evaluated in the first series of tests. It was found that the peak overpressures were reduced by only about 7 per cent, and that arrival times were delayed by about 1 millisecond.

Probably the most important measurements made were those of the magnitude and duration of any portion of the blast wave which bypassed the valve. Because the valve was not completely closed at the time of arrival of the blast wave at the closure port (Figure 9), fairly high peak values of pressure did bypass. The durations were very short, however, and when the bypassed wave is compared to the applied wave the valve was quite effective. Such a comparison is made in Figure 10. The ratios of the areas under the curves show that at approximately 100 psi overpressure less than 0.1 per cent of the applied impulse passed by the valve. The bypassed wave had a typical peak value of 15 psi, a positive duration of approximately 3 milliseconds, and a positive impulse of about 0.03 psi-sec. The positive phase was followed by a negative phase with a peak of 9 or 10 psi and a duration of approximately 7 milliseconds. There was then some oscillation

of the wave about atmospheric pressure before it damped out. There are no known tests with this type of wave form on filters, and the impulse of the wave may be below that which causes filter damage.

CONCLUSIONS

1. At 600 cfm the pressure drop through a prototype of the valve described herein would probably be about 1 inch of water.

2. The overpressures developed in the valve, including reflected pressures, would be equal to or less than the outside air overpressures. The wave forms would, however, be somewhat different.

3. The blast trap tested was not sufficiently effective to warrant its continued use.

4. The valve body was amply strong to withstand numerous loadings at 100 psi. It might even be possible to utilize thinner walls on a prototype.

5. Both of the flaps tested were strong enough to take several loadings at 100 psi overpressure. The inertia of the flap will have to be reduced, however, if at low pressures it is to be completely closed upon the arrival of the blast wave at the closure port.

6. Flap rebound is a problem.

7. A small portion of the applied overpressure bypassed the valve. It was of very short duration, but requires further investigation before the valve can be connected directly to existing filter systems.

8. The valve as described herein could certainly be used with a relatively small plenum and has the advantage of simplicity of operation.

ACKNOWLEDGMENTS

The author wishes to gratefully acknowledge all of the technical contributions and encouragement received from numerous persons at NCEL, particularly Mr. E. N. Hellberg. The air-flow tests were all conducted under his supervision and the related information contained in the report was obtained from his memorandum.

Also deserving acknowledgment are Mr. H. R. Joerding for setting up and conducting the air-flow tests; Mr. T. J. Landrum and Mr. C. J. Smith for their assistance in setting up and conducting the blast simulator tests; and Mr. W. Q. Ginn for his continued assistance including the reducing, compiling, and plotting of the data and the preparation of the figures.

Special thanks goes to Mr. S. L. Bugg, Director of the Structures Division during most of the period covered by this report, for his guidance and assistance, and for allowing the author to pursue and develop an idea which would normally not fall within the scope of the Structures Division's mission.

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APPENDIX

FUTURE WORK

A large number of approaches were considered for the continued development of a blast-closure valve with the desired characteristics. The effect of each approach on the desirable characteristics, as discussed in the introduction of the report, was carefully considered. The approach chosen was selected by a process of elimination. Operational simplicity was held to be of paramount importance.

The fact that the valve is only part of a ventilation system was kept in mind. It was also noted that the 100 psi overpressure level is within the fireball of a 5-megaton surface burst, and that even outside of a fireball the air temperatures could be very high.

Thermal considerations or an increase incomplexity were the basis for elimination of the majority of approaches considered.

Since none of the methods to eliminate or reduce the rebound of the flap were completely desirable, it appears that there will be a small bypassed wave to cope with. This may, however, not be too much of a problem. Even though experimental data on area changes is very limited, BRL Report No. 1390 indicates that the transition from an 8-inch pipe to a 24-inch square duct (size of a 600-cfm filter) might reduce a 15 psi overpressure to about 3 psi. A muffler or some other attenuation device could reduce this still further.

Present plans for the immediate future are to improve the valve by:

1. Fabricating lighter flaps to reduce closure time.

2. Making a muffler to attenuate the bypassed wave.

3. Performing tests in the blast simulator on a complete set-up (including a prefilter) to evaluate the system.

Also, drawings will be made of a modified version of the valve which would minimize flap closure problems. In this concept the flap would be placed at the mid-height of the valve. The valve body would taper inwards

from the top and bottom toward the flap, so that the arms of the flap could be made quite short. The valve body would also taper outwards from the top and bottom, so that the flap axis would be long and the total area of the air passage-way would be at least equal to the area of the intake pipe. The flap however would have a considerably smaller moment of inertia.